CONF-80[illegible]1

MASTER

DETECTION, DIAGNOSIS AND PROGNOSIS IN GEOTHERMAL WELL TECHNOLOGY

A. F. Veneruso and Hsi-Tien Chang
Geothermal Technology Division 4742
Sandia National Laboratories
Albuquerque, NM 87185

Abstract: For successful and safe operation of a geothermal well, the condition of the casing and cement must be accurately determined. Measurements on casing wall thickness, corrosion damage, holes, cracks, splits, etc., are needed to assess casing integrity. Cement bond logs are needed to detect channels or water pockets in cement behind pipe and to determine the state of the cement bond to the pipe and formation. Instrumentation for making such measurements is limited by the temperature capabilities (<175°C) of existing logging equipment developed for the oil and gas industry. This paper reviews the instruments that are needed for geothermal casing and cementing inspection, identifies the principle deficiencies in their high temperature use, and describes Sandia's upgrade research program on multi-arm caliper and acoustic cement bond logging tool. The key electronic section in a multi-arm caliper will consist of 275°C circuits designed by Sandia. In an acoustic cement bond logging tool, a simple circuit with possibilities of using commercially available components for high temperature operation is being developed. These new tools will be field tested for operation at a minimum temperature of 275°C and pressure of 7000 psi for up to 1000 hours.

Key words: Casing inspection; cement bond logging tool; geothermal technology.

Introduction: Downhole conditions very often cause casing and cementing problems in geothermal wells as illustrated in Figure 1. Proper engineering development and production of a geothermal field requires periodic inspection and evaluation of the wellbore's casing and cementation. According to a recent study by Knutson and Boardman (1978), the most common tools for assessing casing integrity are spinner surveys, radioactive tracer surveys, electromagnetic surveys, and calipers. The logs commonly used to evaluate cement bond are temperature logs, nuclear cement logs, noise, and acoustic cement bond logs (CBL).

DISCLAIMER

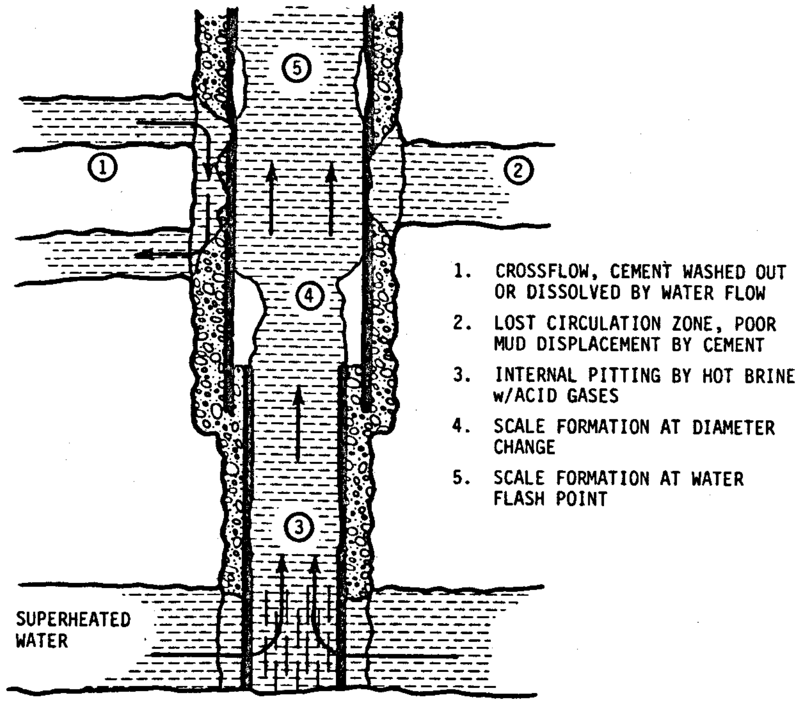

Figure 1. Casing and Cementing Problems in a Geothermal Well

A spinner-type flowmeter responds to and locates fluid flow through holes in the casing. Fluid leakage sometimes also causes temperature anomalies. A differential temperature log describes the slope of the absolute temperature curve and is capable of pinpointing these anomalies even though they may be minute. Sandia National Laboratories has developed prototypes of the flow tool and the temperature tool for operation up to 275°C. (Veneruso, 1979). All the component parts for these tools will soon become commercially available.

Radioactive tracer surveys are useful in locating casing leaks by logging the movement of injected tracers. These surveys are very useful in detecting low flow rate leaks.

Commercially available downhole electromagnetic surveys utilize a coil for generating a magnetic field. The phase changes detected by the receiving coil are related to the casing wall thickness. If the inner diameter is known (this can be measured by a caliper), then the electromagnetic surveys will reveal the outer diameter's condition and thereby indicate the extent of pipe wear and corrosion.

Caliper tools have multiple expanding arms that make contact with the casing walls. The diamter recorded is that of a circle described by the tips of the arms. The caliper log is useful in analyzing corrosion damage, scale buildup, collapsed and parted casing, and casing breaks.

In oil and gas wells, a temperature log is also used to detect the cement top when the hydrating cement undergoes an exothermic reaction that provides a temperature anomaly. Unfortunately, temperature anomalies are common in geothermal wells, and therefore, the interpretation of cement tops is ambiguous. Also, this log must be run while the cement is reacting because afterward thermal equalibrium is achieved and no information can be obtained about the position of cured cement behind the pipe.

The nuclear cement log functions as a modified density log. If there is a density contrast between the cement and the mud or fluid being displaced by the cement, the log provides an estimate of the amount of cement fill at any position in the well by indicating the material density.

The noise log is a display of high frequency sound being produced at any vertical location in the wellbore. An evaluation of this log can pinpoint areas in a well where fluid flow channels occur behind the pipe.

The acoustic CBL tool determines the quality and extent of the physical bond between the casing pipe and the surrounding cement sheath, and between the cement and formation. This log measures the amplitude of the acoustic signals from the casing pipe and the amplitude of a later arrival which reflects the cement bound to the formation.

There are currently no commercially available high temperature cement bond and casing integrity logging systems for geothermal wells with maximum temperatures in excess of 275°C. Most commercial logging tools become unreliable above 175°C in actual field tests. As a consequence, operators must cool the well in order to run surveys. The thermal shock in cooling could cause well damage. Also, loss in production time is expensive. Therefore, high temperature logging capabilities are needed for rapid development of geothermal energy.

Sandia's R&D objective is to develop and commercialize high temperature tools for operation up to 275°C. The technology must be adaptable to the industry to stimulate the development of a large enough market such that commercial suppliers and logging companies can provide the required hardware services on a routine basis. Although the tools described above all provide information on casing and cementing conditions, the multi-arm caliper and acoustic CBL tool are the most versatile and widely used tools in the field. For this reason, we select them as our first set of tools for upgrading.

Table 1 summarizes casing and cementing inspection tools, their limitations in geothermal applications, and the recommended upgrading procedures. The following section will describe the upgrade procedures on a multi-arm caliper and an acoustic CBL tool in more detail.

Sandia's Upgrade Research Program: 1. Multi-arm Caliper - The casing caliper utilizes a single conductor cable plus ground for all power and data transmission. This is accomplished through a multiplexer built into the tool's electronics. The tool uses potentiometers that convert the motion of mechanical arms into electronic signals that are proportional to the casing pipe's inside dimensions. In general, commercially available calipers are specified for operation up to 175°C, because of the temperature limitations of their electronic circuits, DC motors and dynamic seals. Therefore, we propose to use high-temperature-rated linear or rotary displacement transducers (LTDs or RDTs), if high temperature potentiometers cannot be found. As shown in Figure 2, the tool's electronics will consist of a high temperature voltage-to-frequency converter, pulse stretcher, line driver, voltage regulator and a multiplexer. These 275°C circuits were designed by Sandia and will be manufactured by Teledyne and General Electric-Houston. Additional R&D may be necessary to develop the high temperature DC motor that is used to retract the caliper's mechanical arms. In addition, high temperature elastomeric seals or metal bellows may be required to prevent brine from entering the tool's electronic and motor's housing compartment.

2. Acoustic CBL Tool - Figure 3 illustrates the cement bond sonde and the related signals. Casing suspended freely, i.e., uncemented, in a well transmits sound energy with relatively little weakening of the vibrations between the transmitter and receiver. However, when hardened cement is behind the casing and when this cement is properly bonded to the pipe and formation, the vibrations sent out from the tool to the casing will impart similar motion in the cement but at a lower velocity. From the strength and the time of the vibrations received, one can determine the degree of cement bonding. A recording of the free pipe is presented on each log as a reference for evaluating the other signals (Figure 4). In the variable density log, strong casing signal and weak formation signal is an indication of free pipe.

TABLE 1

TOOLS COMMONLY USED FOR CASING INSPECTION AND CEMENT BOND EVALUATION

Tools	Geothermal Limitations	Upgrade Recommendations
Casing Inspection Spinner Survey	None - Technology is available	None - only field test verification
Radioactive Tracer	Operating Temperature <175°C Possible Environmental Impact	Design high temperature circuit
Electromagnetic Tool	Operating Temperature <175°C	Redesign circuits using high temperature electronics
Caliper	Operating Temperature <175°C	Use high temperature electronics Select high temperature dynamic seals Develop high temperature motor Or use mechanical design to eliminate motor and thus the need of dynamic seals
Cement Bond Evaluation Temperature Tool	None - Technology is available Mainly for locating cement top and major void	Extend into a differential temperature logging tool for casing inspection
Nuclear CBL Tool	Operating Temperature <175°C Possible Environmental Impact	Develop high temperature op amp and detector
Noise Tool	Subject to Operator's Interpretation Operating Temperature not crucial (not being used in production wells)	
Acoustic CBL Tool	Electronics limited to <175°C	Develop high temperature SCR Replace circuit with high temperature electronics

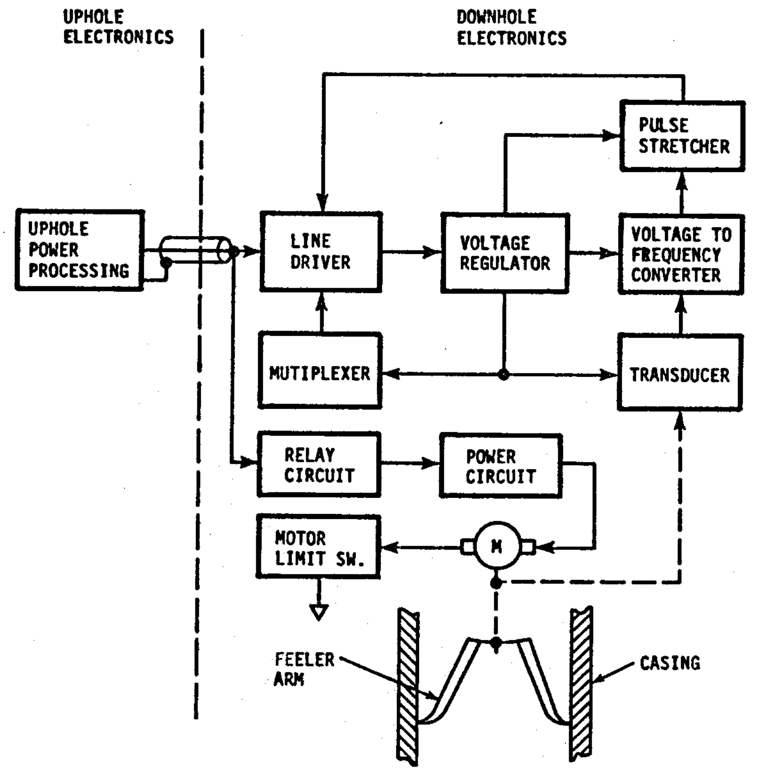

Figure 2. Block Diagram for a Caliper

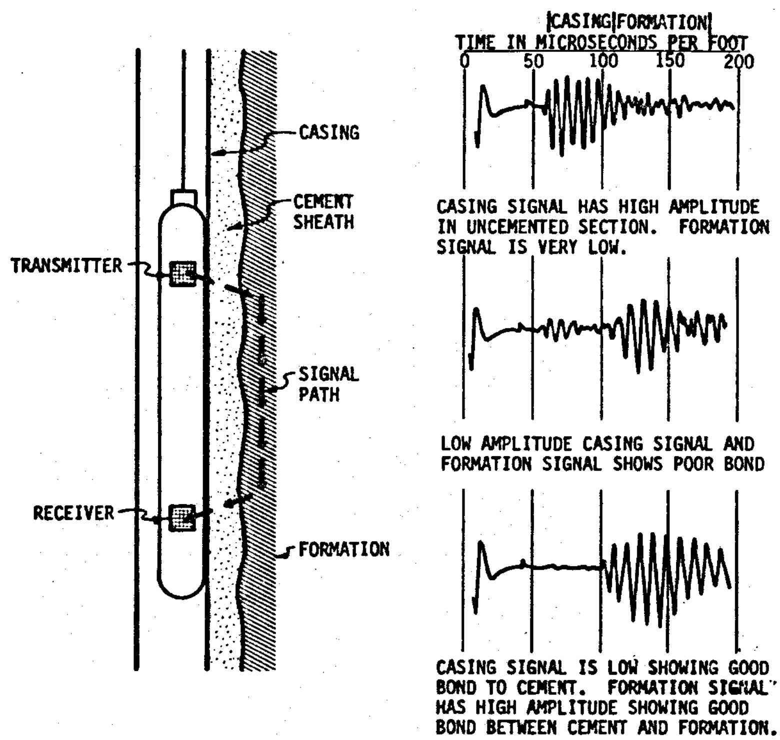

Figure 3. Cement Bond Sonde and Acoustic Signal

A well bonded casing with good cement-to-formation bond will show strong formation signal and weak casing signal.

Some of the commercial CBL tools contain very complex electronic circuits. These systems use many sensors and require complex circuitry in order to provide precise clocking time and signal transmission under a wide variety of conditions in oil and gas wells. However, it is extremely difficult to upgrade a sophisticated circuit for high temperature operation since most commercial electronics are specified for operation only up to 175°C. Therefore, a simplified CBL circuit is essential before any upgrading can take place. In an acoustic CBL tool for operation in geothermal fluid, a single transmitter and a single receiver with adequate spatial separation should provide sufficient information about cement bond condtions in the well. Also, in order to minimize the downhole electronics, signal processing and data reduction will be done uphole.

Figure 5 is an example of a straightforward circuit that is capable of generating a short high voltage, high current pulse for an acoustic transmitter at room temperature. Here, C_1 is used to supply energy to the SCR switch and the acoustic transmitter when the line driver cuts off input power. L_1 is used to boost the voltage at C_1. When the SCR conducts, L_1, L_2, and C_2 prevent the ripples from feeding back to the input. To provide a reference for the returned signal, the input line detects the transmitting time through C_4. R_1, R_2, and C_5 limit the imposed voltage on the unijunction transistor which will not be triggered until the capacitor C_3 is sufficiently charged. Thus, the R_3 C_3 time constant will determine the firing frequency of the SCR. Transformer T sharpens and boosts the amplitude of the trigger pulse to the SCR. On Figure 5 we have not specified component's values because their values would be different for different acoustic transducers and temperature ranges. We are currently working to develop a high temperature version of this circuit.

Commercial SCRs (Semiconductor Controlled Rectifiers) rated at 175°C or lower place a limitation on a tool's operating temperature. We have initiated a project to upgrade the SCR for operation at 275°C. It is expected that the theory and optimal fabricational approach will be determined by September 1981 and a "GaP" or "GaAs" SCR will be ready in prototype by October 1982. We are also exploring the possibility of combining a thermoelectric cooler with an SCR in order to run the unit in an ambient of 275°C while the temperature of the SCR chip is only 175°C. Commercial vacuum tubes, such as sprytrons and thyratrons, are other possibilities that

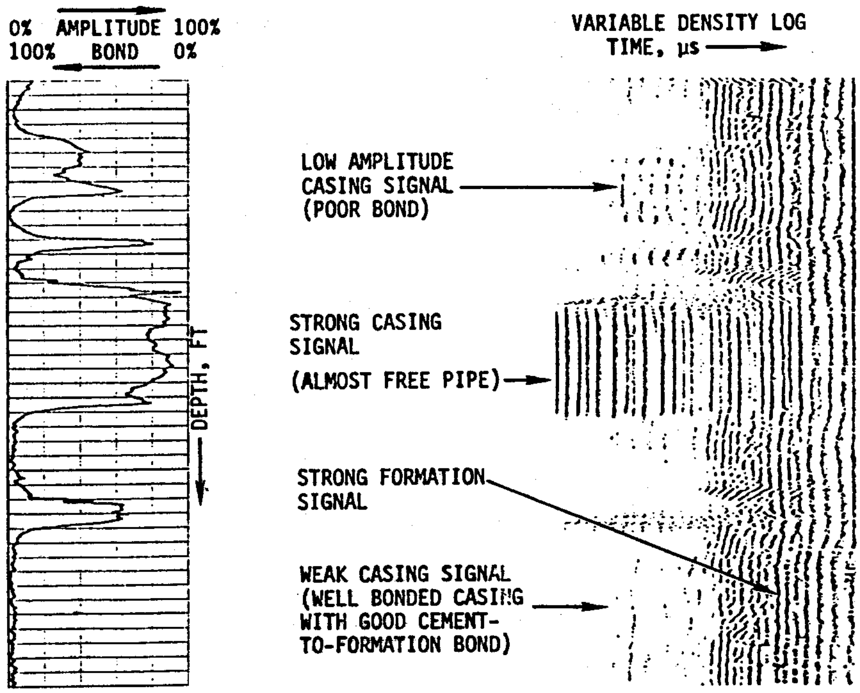

Figure 4. Acoustic Cement Bond Log

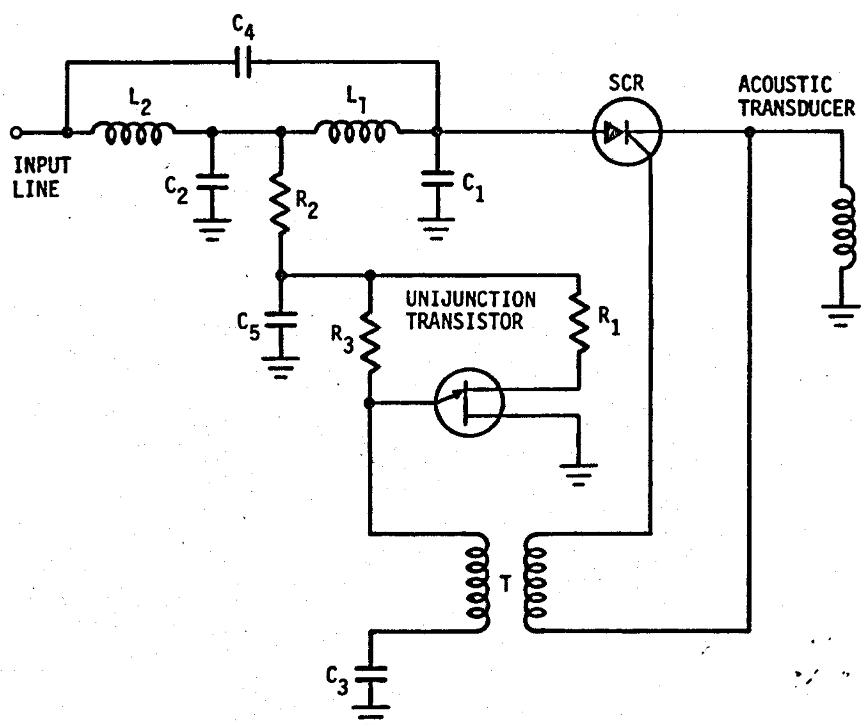

Figure 5. Cement Bond Transmitter Schematic

might be used as a substitute for an SCR. In these options, the shortcoming is in the limited number of shots that can be guaranteed; we are investigating the possibility of modifying a tube's design for longer life time.

Return signals at the receiver must be amplified so that they can be detectable uphole. Specially selected commercial junction field effect transistors (JFETs) can withstand high temperature and will be considered. Another possibility is the electronic tubes. Although, an electronic tube amplifier may operate stably only up to 250°C as reported by Cannon (1979), development of integrated thermionic circuits has resulted in a much higher operating temperature (McCormick and Wilde, 1980). In addition, Harris Semiconductor Corp. is working under contract with Sandia to develop a high-temperature operational amplifier (Ohr, 1980). Other commercial products that may be used to upgrade a tool for geothermal application is summarized in Table 2. For a step-by-step 275°C fabrication technology, one may refer to a report by Bonn and Palmer (1980).

Summary: In this report, we describe a project to upgrade a multi-arm caliper and an acoustic cement bond logging tool for operation at a minimum temperatue of 275°C and pressure of 7000 psi for up to 1000 hours. The commercially available materials and devices, and the electronic components developed by Sandia National Laboratories for high temperature operation will be fabricated and field tested in partnership with industry. The final stage of this project is to commercialize the design and transfer the technology to industry.

TABLE 2

MAXIMUM OPERATING TEMPERATURE FOR SOME COMMERCIAL PRODUCTS

Company	Item	Maximum Temperature
	<u>Resistors</u>	
Caddock Electronics	Thick Film Chips	500°C
Cermalloy	Thick Film Inks	500°C
	<u>Capacitors</u>	
Philips (MEPCO)	Solid Aluminum Electrolytic	300°C
Custom Electronics	High Voltage	300°C
Sprague	Thin Film SiO_2	300°C
Cermalloy	Thick Film Inks	500°C
	<u>Transformers</u>	
General Magnetics	Transformers	500°C
	<u>Conductors</u>	
Permalustre	Anodized Aluminum Wire	500°C
Hy-Temp Transducers	Ceramic Coated Copper Wire	500°C
Cermalloy	Conductor Inks	300°C
	<u>Solder</u>	
DuPont	High Temperature Paste	300°C
	<u>Epoxy</u>	
Ablestick	Conductor or Dielectric	300°C
	<u>Transistors</u>	
Motorola	JFET	300°C
	<u>P. C. Board</u>	
DuPont	Polyimide	300°C
	<u>Packages</u>	
Tekform	Metal Packages	350°C
3M	Ceramic Packages	350°C

REFERENCES

1. Bonn, P. A. and Palmer, D. W., "275°C Thick Film Hybrid Microcircuitry Fabrication Technology," Sandia National Laboratories, SAND80-0078, 1980, available through NTIS, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

2. Cannon, W. L., "Ultra High Temperature Instrumentation Amplifier," System Development Corporation, Santa Monica, California. TM-(L)-6158/006/00, 1980.

3. Knutson, C. K. and Boardman, C. R., "An Assessment of Non-Destructive Testing of Well Casing, Cement and Cement Bond in High Temperature Wells," GeoEnergy Corporation, Las Vegas, Nevada, 1978.

4. McCormick, J. B. and Wilde, D., "Development of Integrated Thermionic Circuits for High-Temperature Applications," High Temperature Electronics and Instrumentation Seminar Proceedings, Sandia National Laboratories, SAND80-0834C, p. 73-75, 1980. Available from NTIS, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, VA 22161.

5. Ohr, S., Analog Circuit Editor, "Dielectrically Isolated Op Amps and Comparators Take High Temperatures," Electronic Design 9, p. 38-40, 1980.

6. Veneruso, A. F., "High Temperature Electronics for Geothermal Energy," IEEE Circuits and Systems Magazine, Vol. 1, No. 3, p. 11-17, 1979.